

A large group of people, likely the STAR collaboration members, are posing for a group photo around the STAR detector at RHIC. The detector is a large, blue, cylindrical structure with a central circular opening. It is surrounded by various support structures, including yellow railings and scaffolding. The people are standing on different levels of the structure, some on the ground and others on elevated platforms. The background shows the interior of a large facility, possibly a tunnel or a large hall.

# STAR at RHIC

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# Outline

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## 1) Introduction

## 2) STAR Physics Program

- *Physics working group*
- *Upgrade programs*
- *Run plan for 2009 – 2013\**

\* As prepared in May 2008

## 3) Summary and Questions



# Physics Goals at RHIC

## RHIC

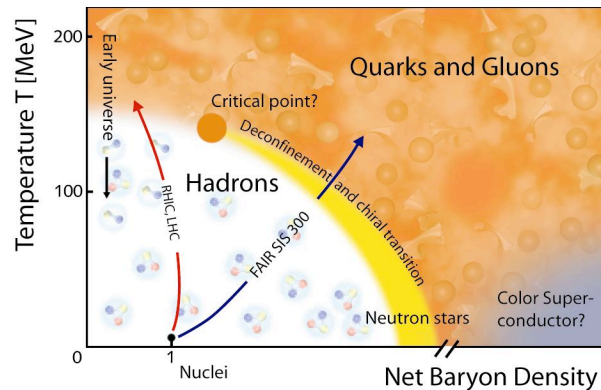
Au+Au, Cu+Cu,  
d+Au, p+p  
at  
200 – 5 GeV

Polarized p+p  
at  
200 & 500 GeV

p+p, d+Au  
pp2pp

- Identify and study the property of matter (EOS) with partonic degrees of freedom.
- Explore the QCD phase diagram.
- Study the origin of spin in  $p$ .
- Investigate the physics at small- $x$ , gluon-rich region.

# STAR Physics Focus

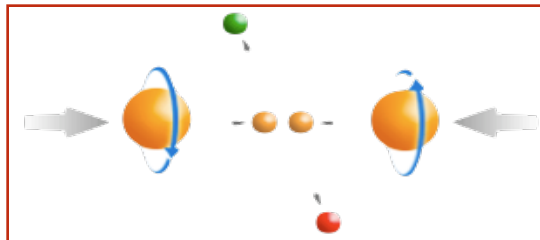


## 1) At 200 GeV top energy

- Study **medium properties, EoS**
- pQCD in hot and dense medium

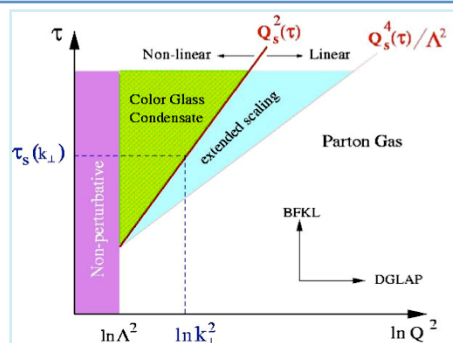
## 2) RHIC beam energy scan

- Search for **critical point**
- Chiral symmetry restoration



## Polarized spin program

- Study **proton intrinsic properties**



## Forward program

- Study low-x properties, search for **CGC**
- Study elastic (inelastic) processes (pp2pp)
- Investigate **gluonic exchanges**

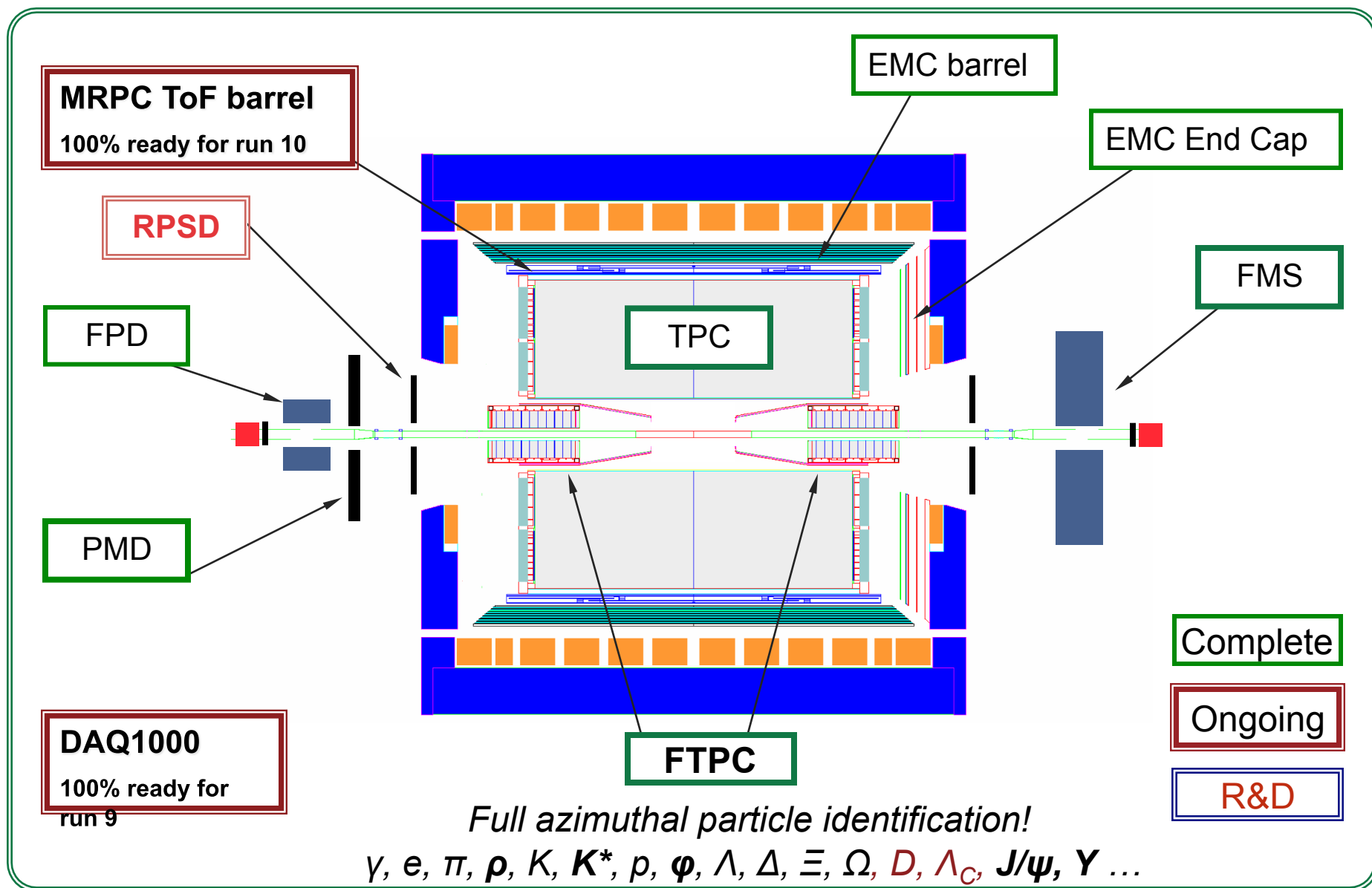


# STAR Physics Working Groups

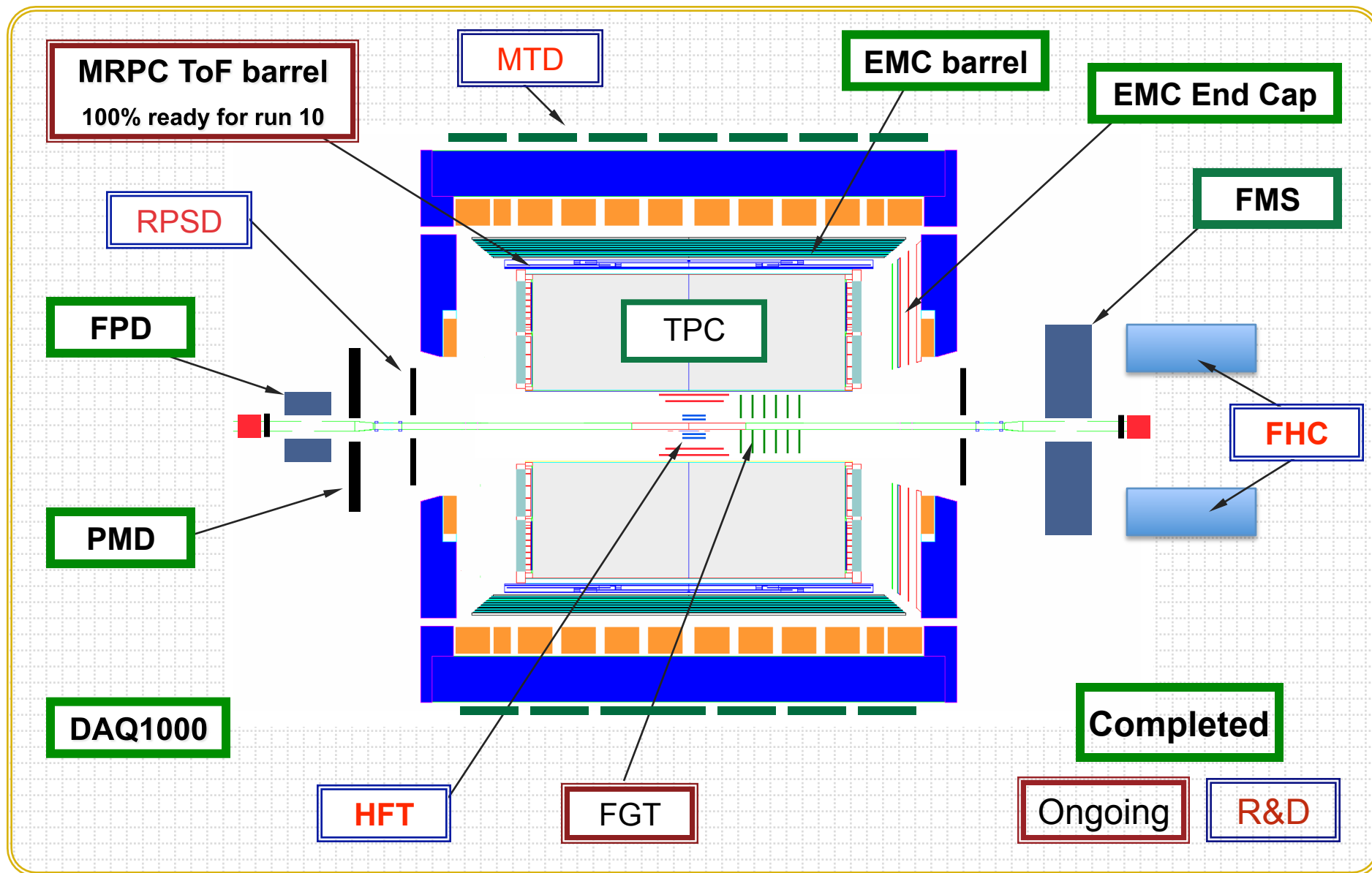
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- 1) **Spin:**  $g$  contribution to spin structure
- 2) **UPC:** UPC, pp2pp
- 3) **Heavy Flavor:**  $c$ -,  $b$ -quark hadrons
- 4) **Light Flavor Spectra:**  $u$ -,  $d$ -,  $s$ -quark hadrons, di-leptons, photons
- 5) **Bulk Correlations:**  $v_1$ ,  $v_2$ , correlations/fluctuations
- 6) **Jet Correlations:** high- $p_T$  triggered correlations

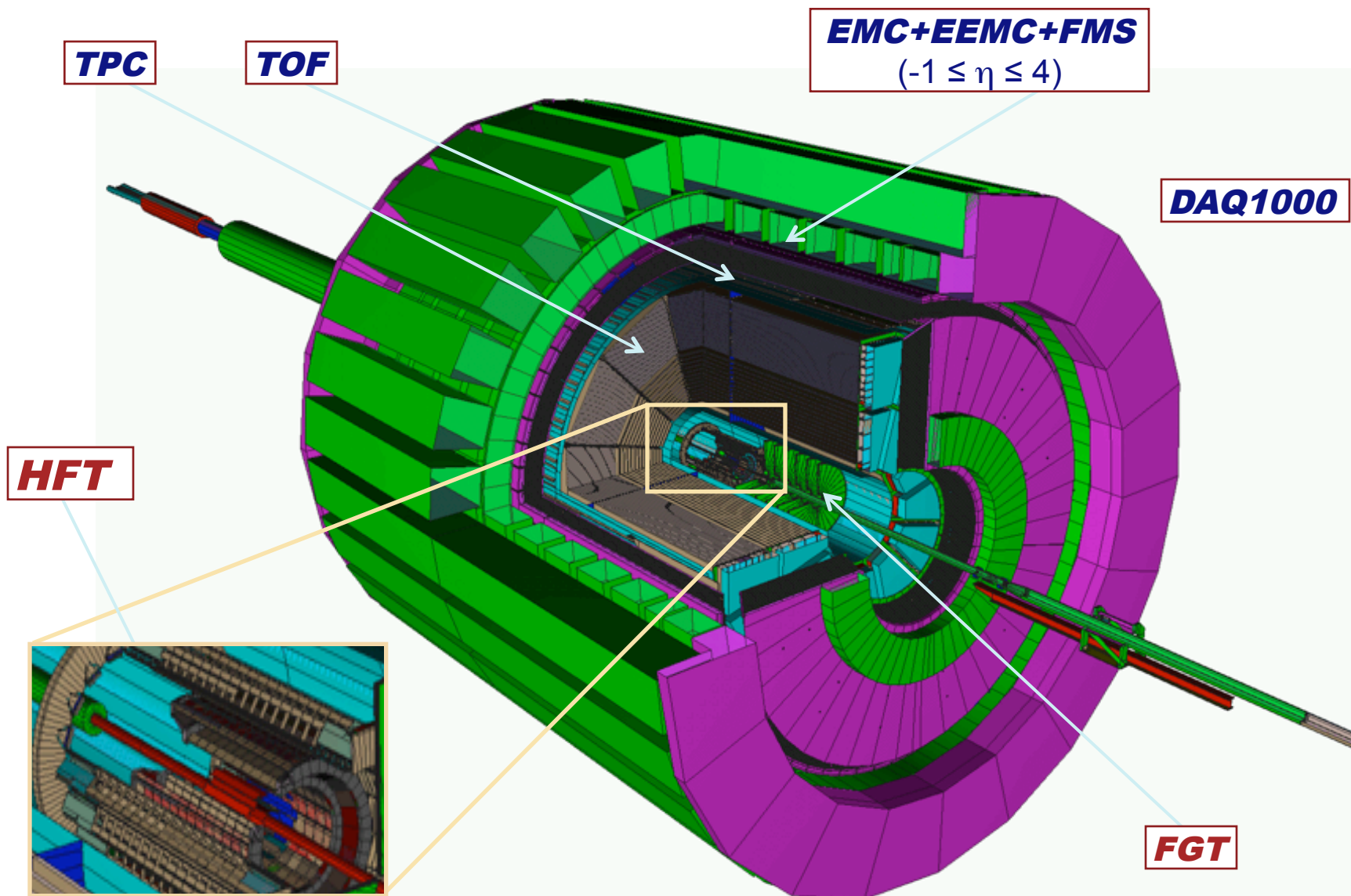
# STAR Detector



# STAR Detector

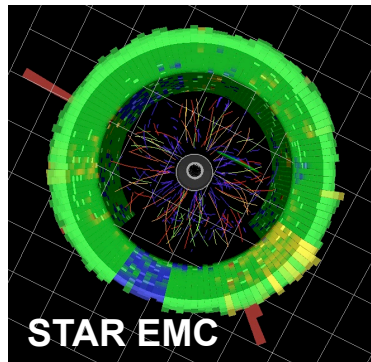
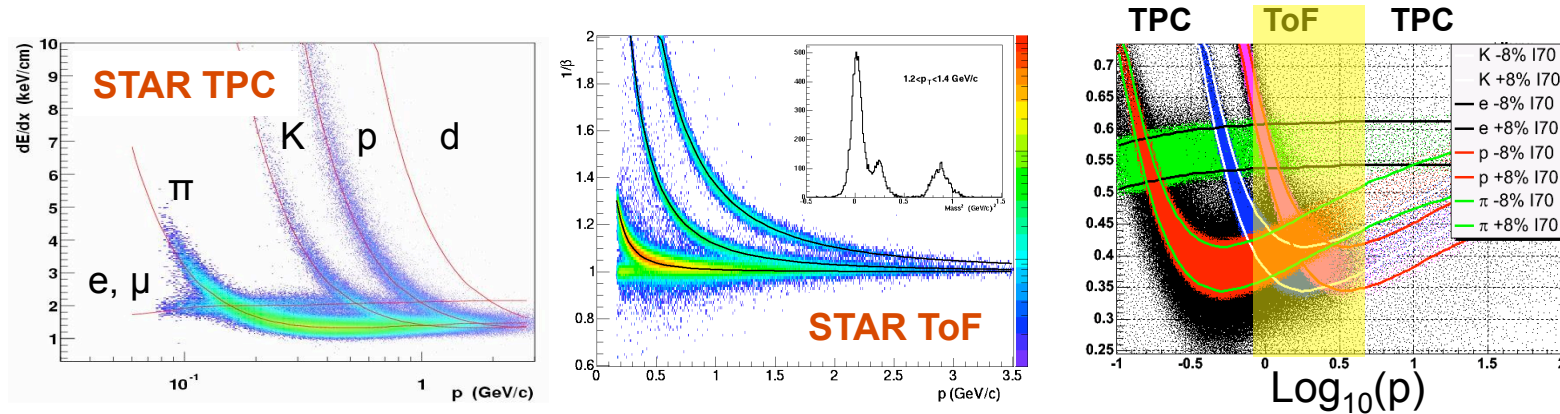


# STAR Detectors: *Full $2\pi$ particle identification!*

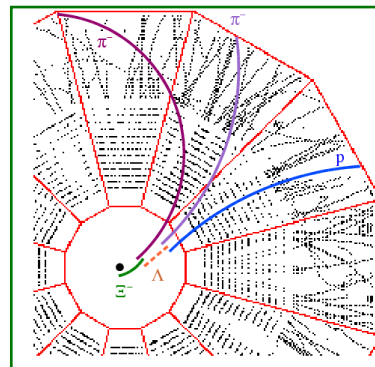




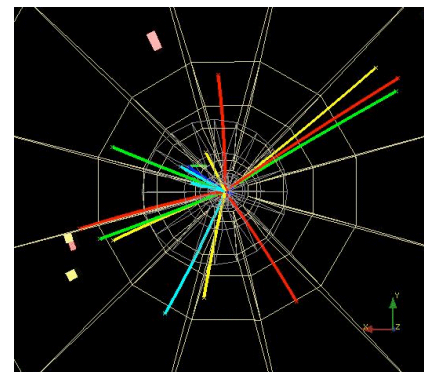
# Particle Identification at STAR



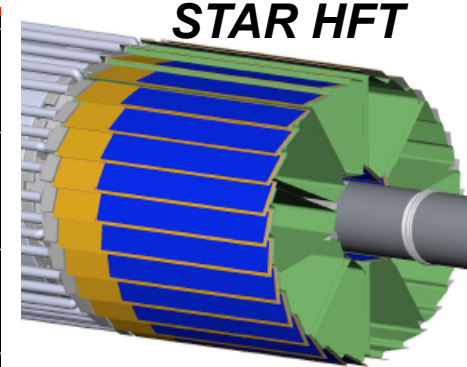
Neutral particles



Strange  
hyperons



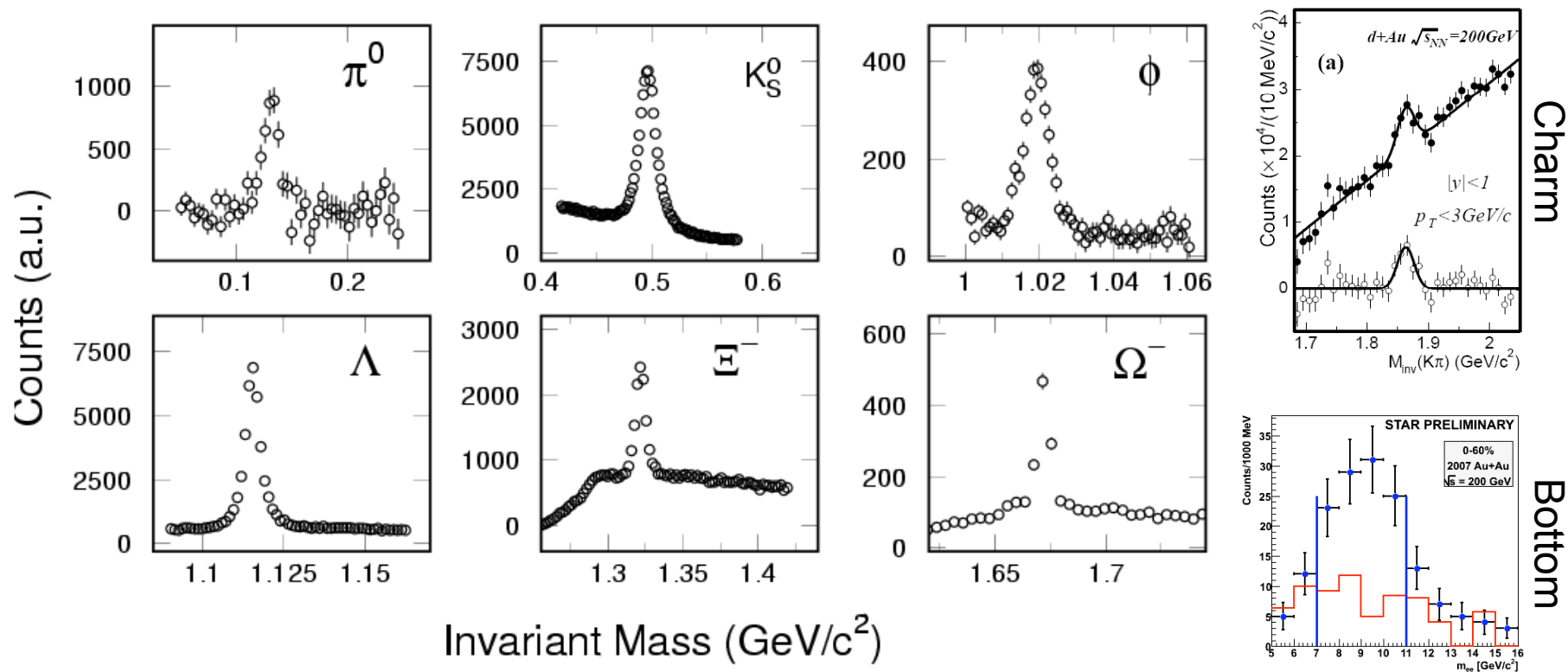
Jets



Heavy Quark  
Hadrons

***Multiple-fold correlations among the identified particles!***

# Particle Identification (ii)

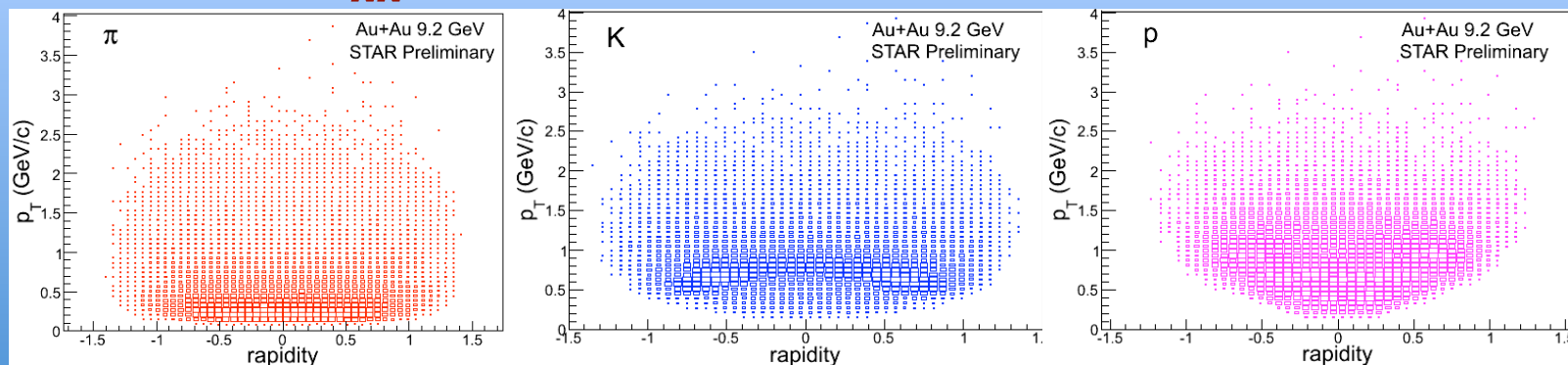


Reconstruct particles in full azimuthal acceptance of STAR!

# Collider Acceptance

Collider Mode STAR

$\sqrt{s_{NN}} = 9.2 \text{ GeV Au+Au Collisions at RHIC}$

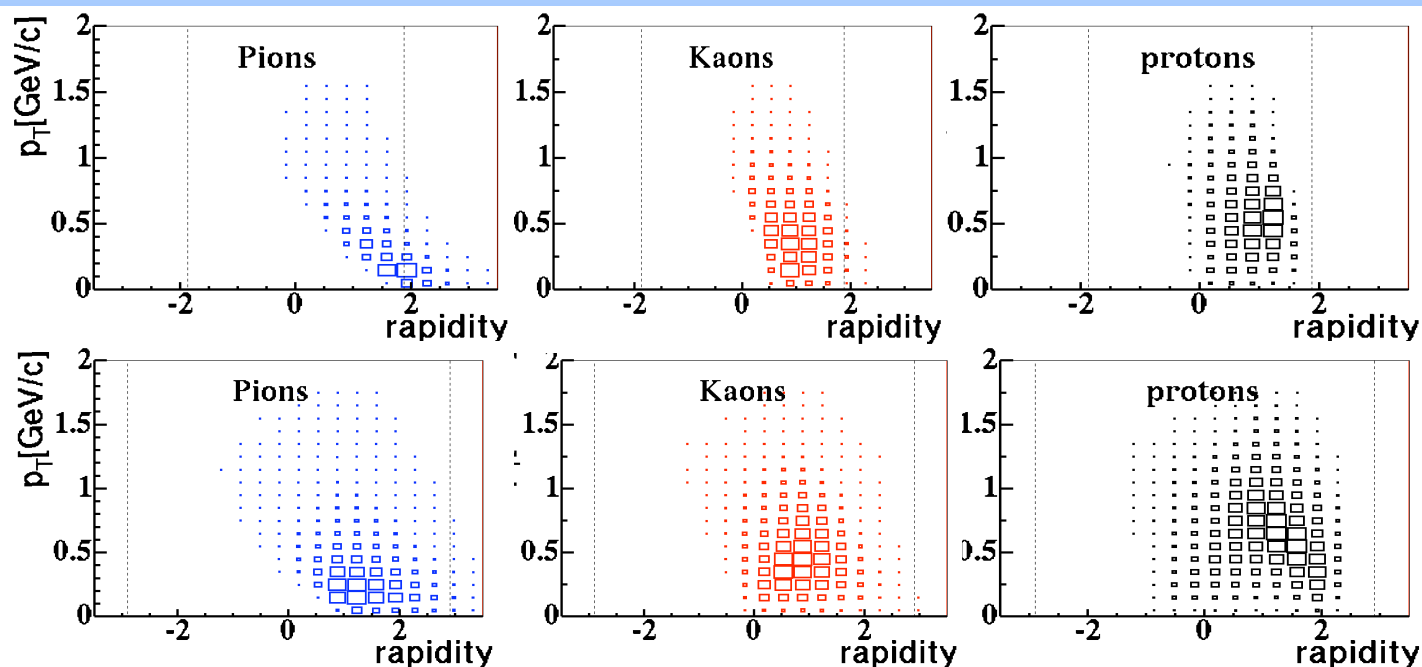


Fix-target Mode NA49

$\sqrt{s_{NN}}$

6 GeV

17 GeV





# sQGP and the QCD Phase Diagram

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In 200 GeV Au+Au collisions at RHIC, strongly interacting matter formed:

- Jet energy loss:  $R_{AA}$
- Strong collectivity:  $v_0, v_1, v_2$
- Hadronization via coalescence:  $n_q$ -scaling

## Questions:

*Is thermalization reached at RHIC?*

- Systematic analysis with  $dN/dp_T$  and  $dv_2/dp_T$  results...
- Heavy quark measurements

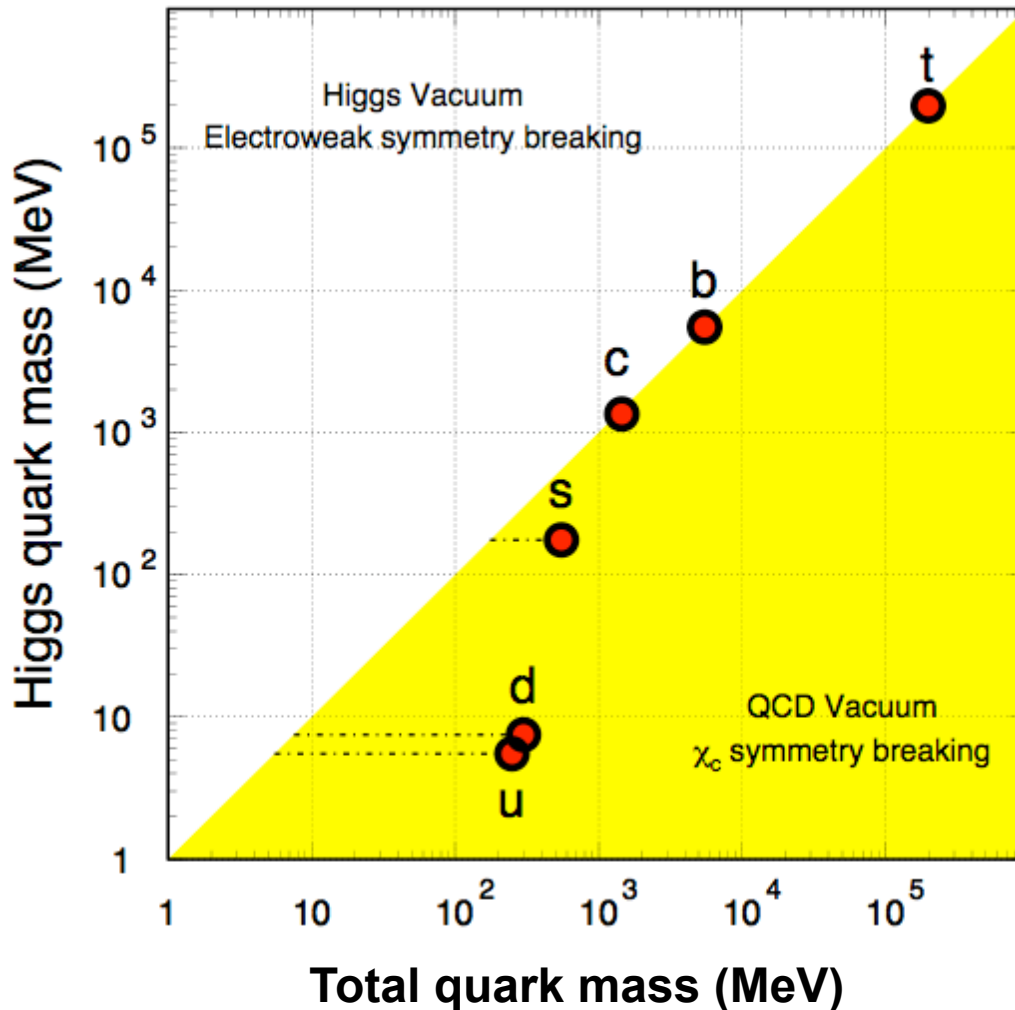
*When (at which energy) does this transition happen?*

*What does the QCD phase diagram look like?*

- RHIC Beam Energy Scan

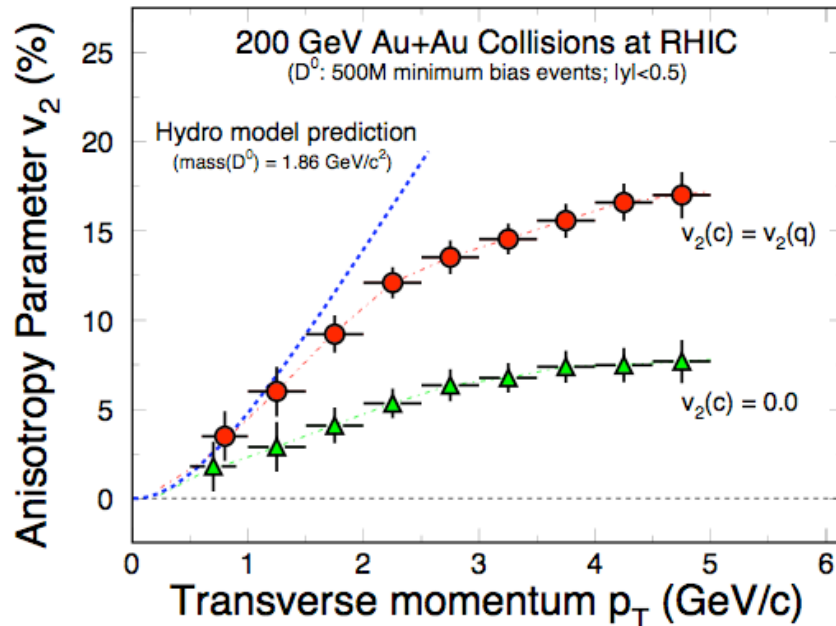


# Quark Masses



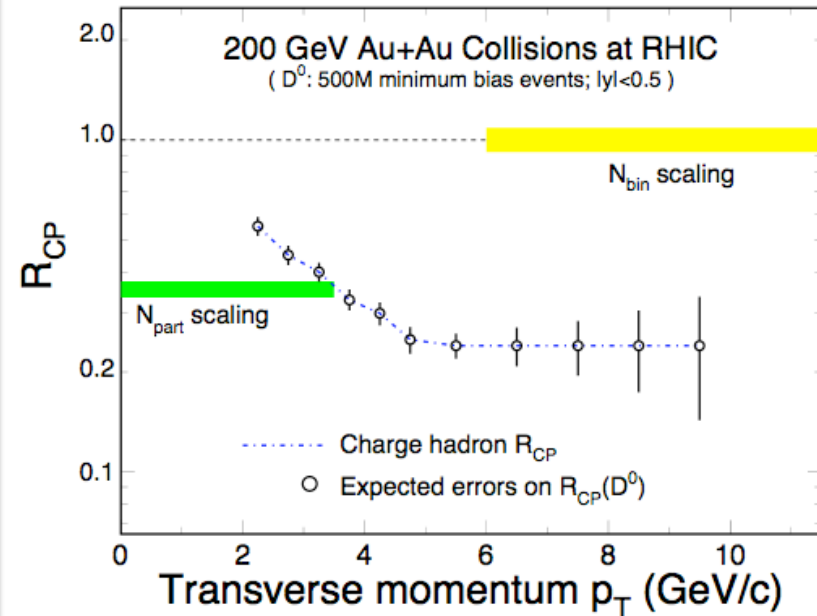
- 1) Higgs mass: electro-weak symmetry breaking. (current quark mass)
  - 2) QCD mass: Chiral symmetry breaking. (constituent quark mass)
- ⇒ New mass scale compared to the excitation of the system.
- ⇒ Important tool for studying properties of the hot/dense medium at RHIC.
- ⇒ Test pQCD predictions at RHIC.

# Charm Hadron $v_2$ and $R_{AA}$



- 200 GeV Au+Au m.b. collisions (500M events).
- Charm hadron collectivity  $\Rightarrow$  drag/diffusion constants  $\Rightarrow$

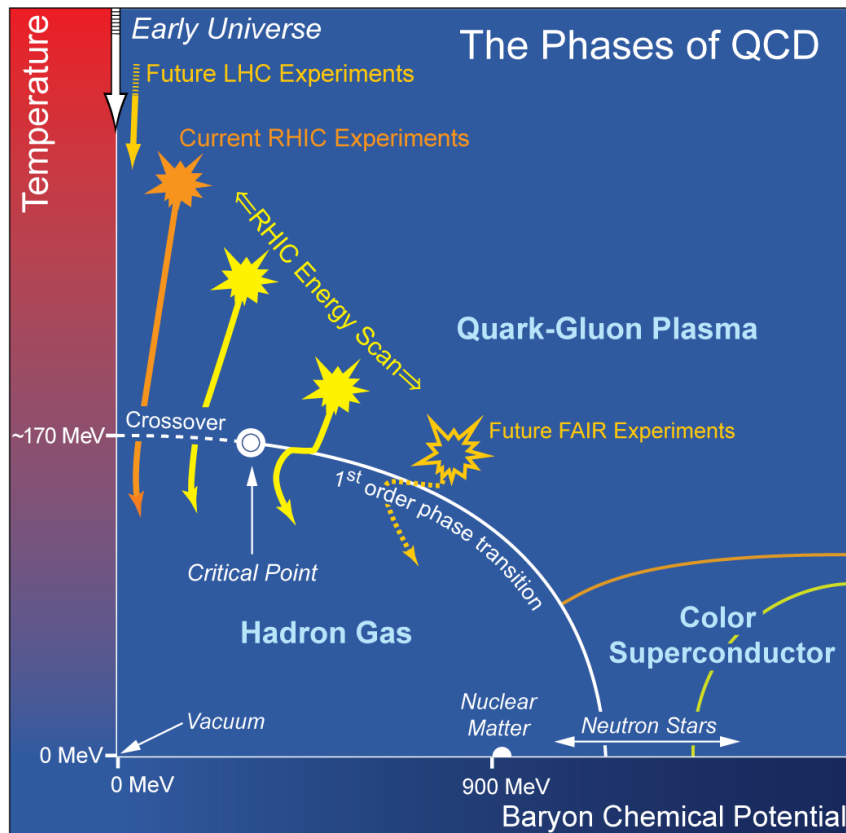
**Medium properties!**



- 200 GeV Au+Au m.b. collisions ( $|y|<0.5$  500M events)
- Charm hadron  $R_{AA} \Rightarrow$

**- Energy loss mechanism!**  
**- QCD in dense medium!**

# The QCD Phase Diagram



**STAR's plan:**

**run10: RHIC Beam Energy Scan**  
**run11: Heavy Quark measurements**

- LGT prediction on the transition temperature,  $T_c \sim 170$  MeV.
- LGT calculation, universality, and models point to the existence of the critical point on the QCD phase diagram\* at finite baryon chemical potential.
- Experimental evidence for either the critical point or 1<sup>st</sup> order transition is important for our knowledge of the QCD phase diagram\*.

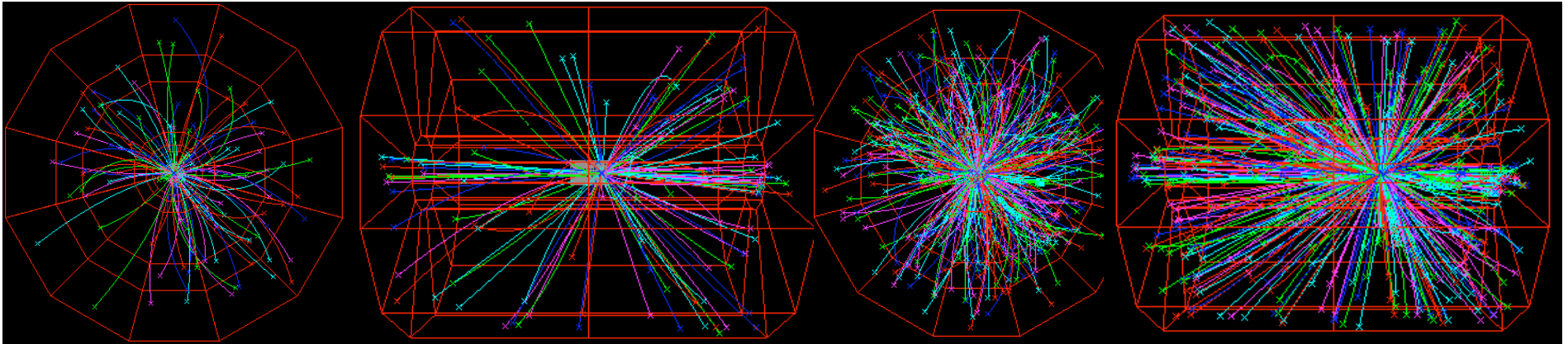
**\* Thermalization is assumed**

Stephanov, Rajagopal, and Shuryak, PRL **81**, 4816(98)

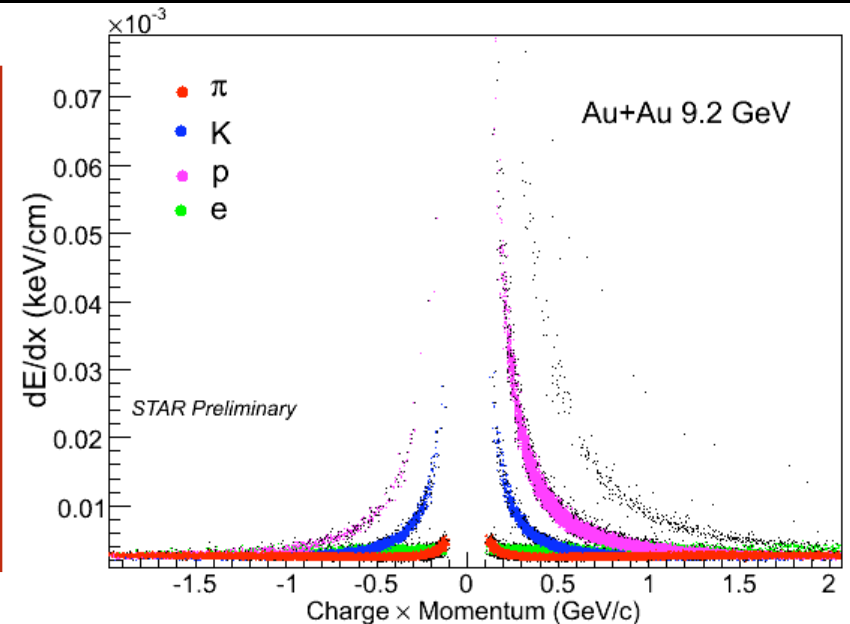
Rajagopal, PR **D61**, 105017 (00)

<http://www.er.doe.gov/np/nsac/docs/Nuclear-Science.Low-Res.pdf>

# Au + Au Collisions at 9.2 GeV



- 1) ~ 3500 collisions collected
- 2) Determine Luminosity
- 3) STAR has preliminary results on:  
Particle identification in TPC; charged multiplicity,  $\pi$ - $\pi$  interferometry, particle spectra and ratios;  $v_1$  and  $v_2$



PID will be further significantly extended using full TOF.

Lokesh SQM08



# Run 9: 25 Cryo-week (scenario I)

STAR priorities for Runs 9 and 10:

- (1) 200 GeV longitudinally polarized p+p -  $\Delta g(x)$
- (2) Beam energy scan down to  $\sqrt{s}_{NN} \sim 5\text{-}6$  GeV  
**- Search for the QCD critical point**

**\*\* C-AD transverse stochastic cooling test important!**

Run	Energy (GeV)	System	Time	Goal
9	$\sqrt{s} = 200$	$p \rightarrow p \rightarrow$	12 week	$50 \text{ pb}^{-1} P^4L 6.5 \text{ pb}^{-1}$
	$\sqrt{s} = 500$	$p \uparrow p \uparrow$	2 week	Commissioning
	$\sqrt{s} = 200$	$p \uparrow p \uparrow$	$\frac{1}{2}$ week	pp2pp
	<b>**</b> $\sqrt{s}_{NN} = 200$	Au + Au	3 week	0.3B minbias, $0.5 \text{ nb}^{-1}$
	$\sqrt{s}_{NN} = 5$	Au + Au	$\frac{1}{2}$ week*	Commisioning
10	$\sqrt{s}_{NN} = 39 - 6.1$	Au + Au	14 week	1 <sup>st</sup> energy scan
	$\sqrt{s}_{NN} = 5$	Au + Au	1 week	Commisioning
	$\sqrt{s}_{NN} = 200$	Au + Au	2 week	200M central
	$\sqrt{s}_{NN} = 200$	Au + Au	1 week	50M central
	$\sqrt{s} = 200$	$p \rightarrow p \rightarrow$	$\frac{1}{2}$ week	pp2pp
	$\sqrt{s} = 500$ or 200	$p \uparrow p \uparrow$ or $p \rightarrow p \rightarrow$	4 $\frac{1}{2}$ week	Spin studies

# Runs 11 - 13 (30 cryo-week/yr)

Run	Energy (GeV)	System	Time	Goal	
11	$\sqrt{s} = 200$	$p_{\uparrow} p_{\uparrow}$ or $p_{\rightarrow} p_{\rightarrow}$	6 week	20-30 pb <sup>-1</sup>	FGT
	$\sqrt{s} = 500$	$p_{\uparrow} p_{\uparrow}$ or $p_{\rightarrow} p_{\rightarrow}$	15 week	150 pb <sup>-1</sup>	
	$\sqrt{s_{NN}} = 200$	U + U	2 week	Commissioning	
12	$\sqrt{s_{NN}} = 200$	Au + Au	12 week	0.5B minbias, 5 nb <sup>-1</sup>	HFT
	$\sqrt{s_{NN}} = 39 - 5$	Au + Au	13 week	2 <sup>nd</sup> energy scan	
13	$\sqrt{s} = 200$	$p_{\uparrow} p_{\uparrow}$ or $p_{\rightarrow} p_{\rightarrow}$	13 week	2B minbias, 100 pb <sup>-1</sup>	
	$\sqrt{s} = 500$	$p_{\uparrow} p_{\uparrow}$ or $p_{\rightarrow} p_{\rightarrow}$	12 week	300 pb <sup>-1</sup>	

Run 11: (i) 1<sup>st</sup> measurement of flavor dependence of sea q/anti-q polarization in the proton at  $\sqrt{s} = 500$  GeV *p+p collisions*  
(ii) HFT engineering prototyping in  $\sqrt{s_{NN}} = 200$  GeV *U+U collisions*

## Run 12: *Anticipating RHIC-II high luminosity*

- (i) 1<sup>st</sup> HFT physics measurements of charm hadron  $v_2(p_T)$  and  $R_{CP}(p_T)$  in  $\sqrt{s_{NN}} = 200$  GeV *Au+Au collisions*
- (ii) Focused energy-scan in the search for the QCD critical point.  
Prior accelerator development is crucial at  $\sqrt{s_{NN}} = 5-6$  GeV
- (iii) gamma-jet and quarkonia states measurements

Run 13: (i) HFT physics reference measurement of charm hadron spectra in  $\sqrt{s} = 200$  GeV pp collisions; complete remaining  $\sqrt{s} = 200$  GeV spin milestones.  
(ii) Measurement of the x dependence of W production at  $\sqrt{s} = 500$  GeV

# Run 09: p+p collisions

Starts on Feb. 2, 2009

500 GeV p+p collisions

- total of 10 cryo-weeks

=> ends on April 5<sup>th</sup>

**5 weeks at 500 GeV**

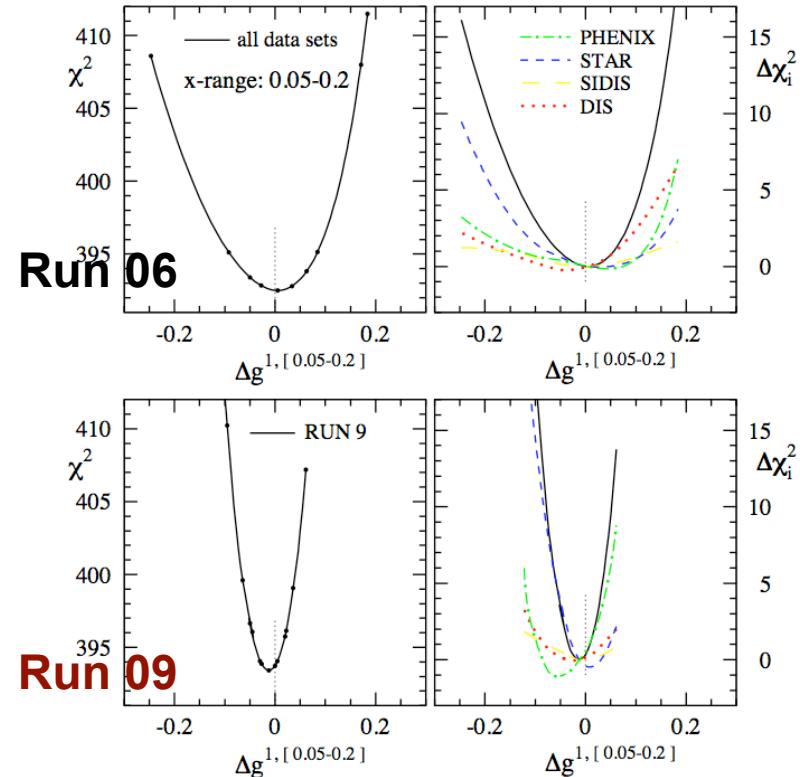
- **IF** sufficient fy09 funds arrives  
total of 22 cryo-weeks =>

**4 weeks at 500 GeV** plus

**11-12 weeks at 200 GeV**

longitudinally polarized  
p+p collisions to measure  
 $\Delta g(x)$  at a FoM: **6.5 pb<sup>-1</sup>**

*de Florian et al, arXiv: 0804.0422*



# Summary

STAR collaboration and its physics program are strong:

- **more** groups join in
- **best** positioned for Exploring the QCD phase diagram
- **best** equipped for  $\Delta g$  measurements at the highest energy polarized proton collider
- **Excellent** for precision measurements and **great** potential for new discoveries

Complementary to ALICE at LHC at higher energy

Complementary to CBM at FAIR at lower energy

## Problems:

- (1) Stable funding for upgrades and beam time
- (2) Need more collaborators to work on detector